Comparison of AHCAL hadron shower data with simulations

Shaojun Lu

shaojun.lu@desy.de

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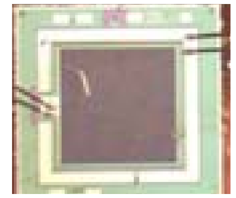
Outline

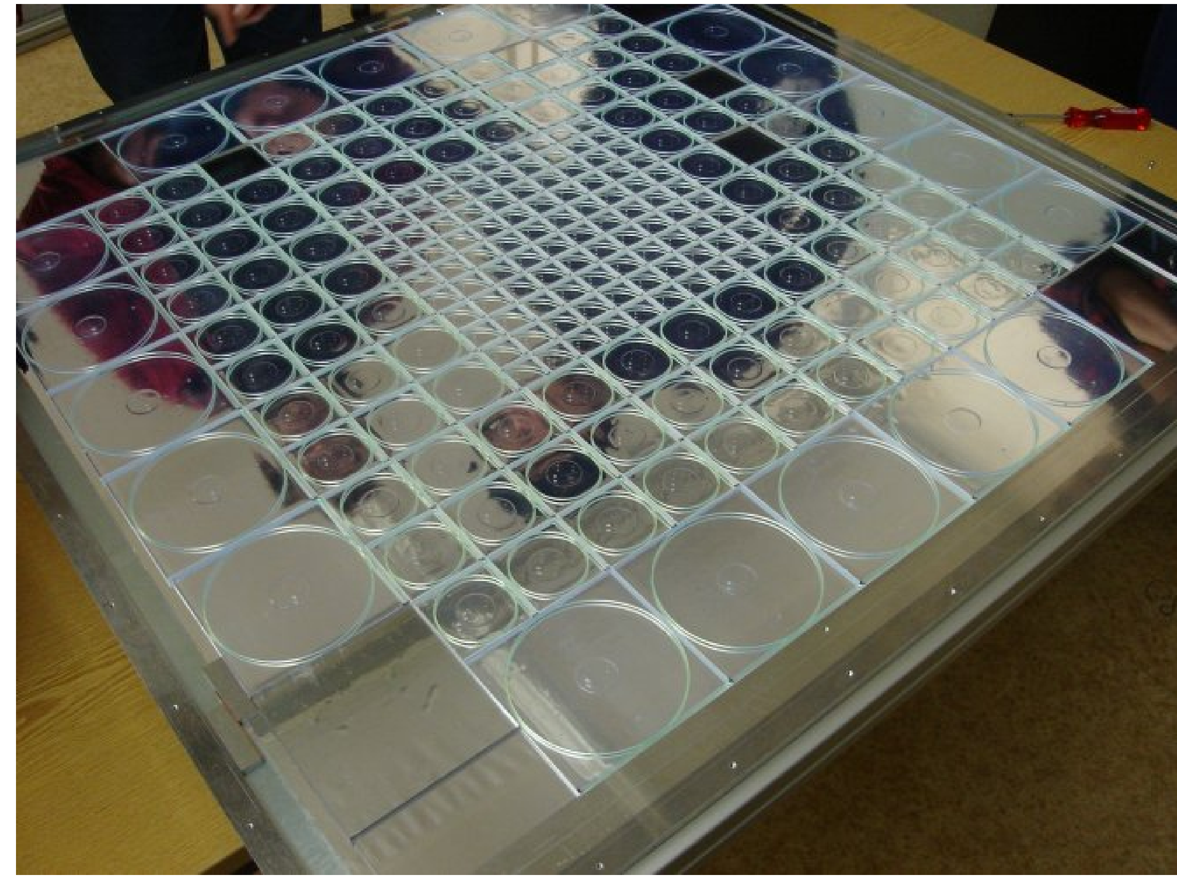
- Test beam prototype
- The power of imaging calorimeter
- Validation with em showers
- Comparison of hadron shower data with simulations
  - Longitudinal shower profile
  - Transverse shower profile
  - Transverse shower containment
  - Mean shower radius
  - Leakage
- Summary

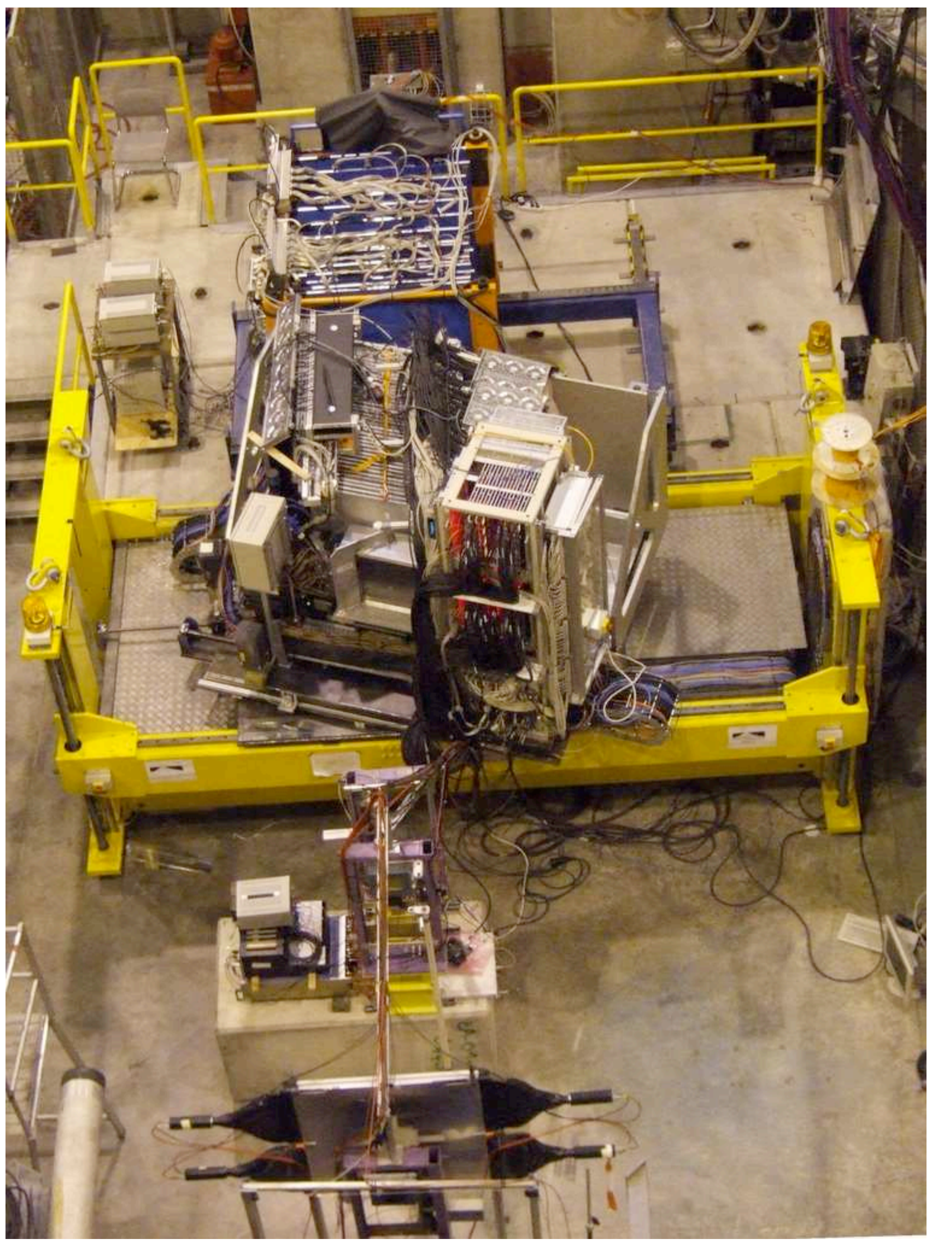
Test beam prototype

- 38 steel layers, 4.5λ
- 7608 tiles with SiPMs



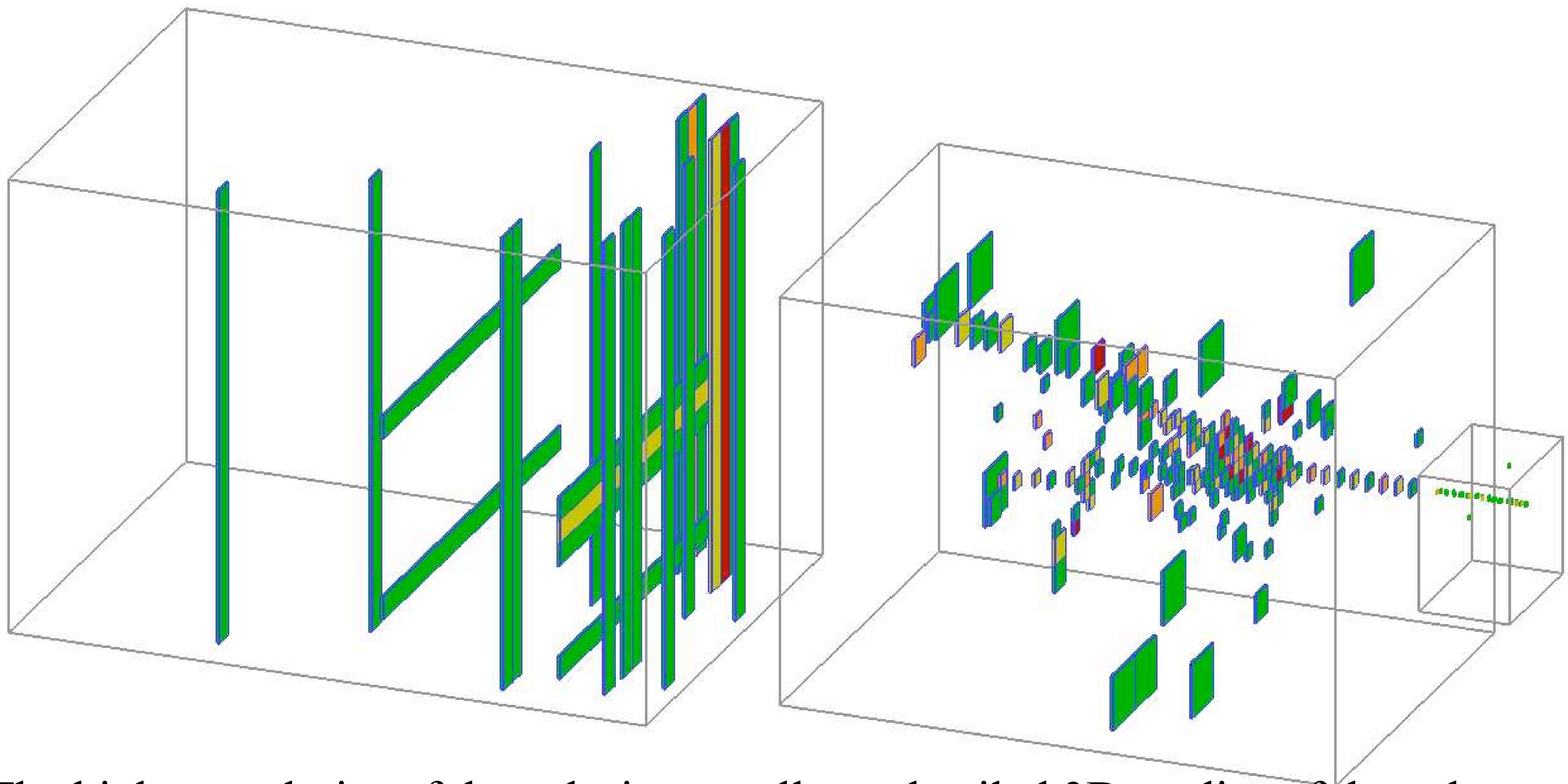
1x1 mm^2 SiPM





- Test at CERN 2006-07, FNAL 2008-09
- Energies: 1 GeV - 180 GeV
- Particles: $\pi^{\pm}$, $e^{\pm}$, p, μ

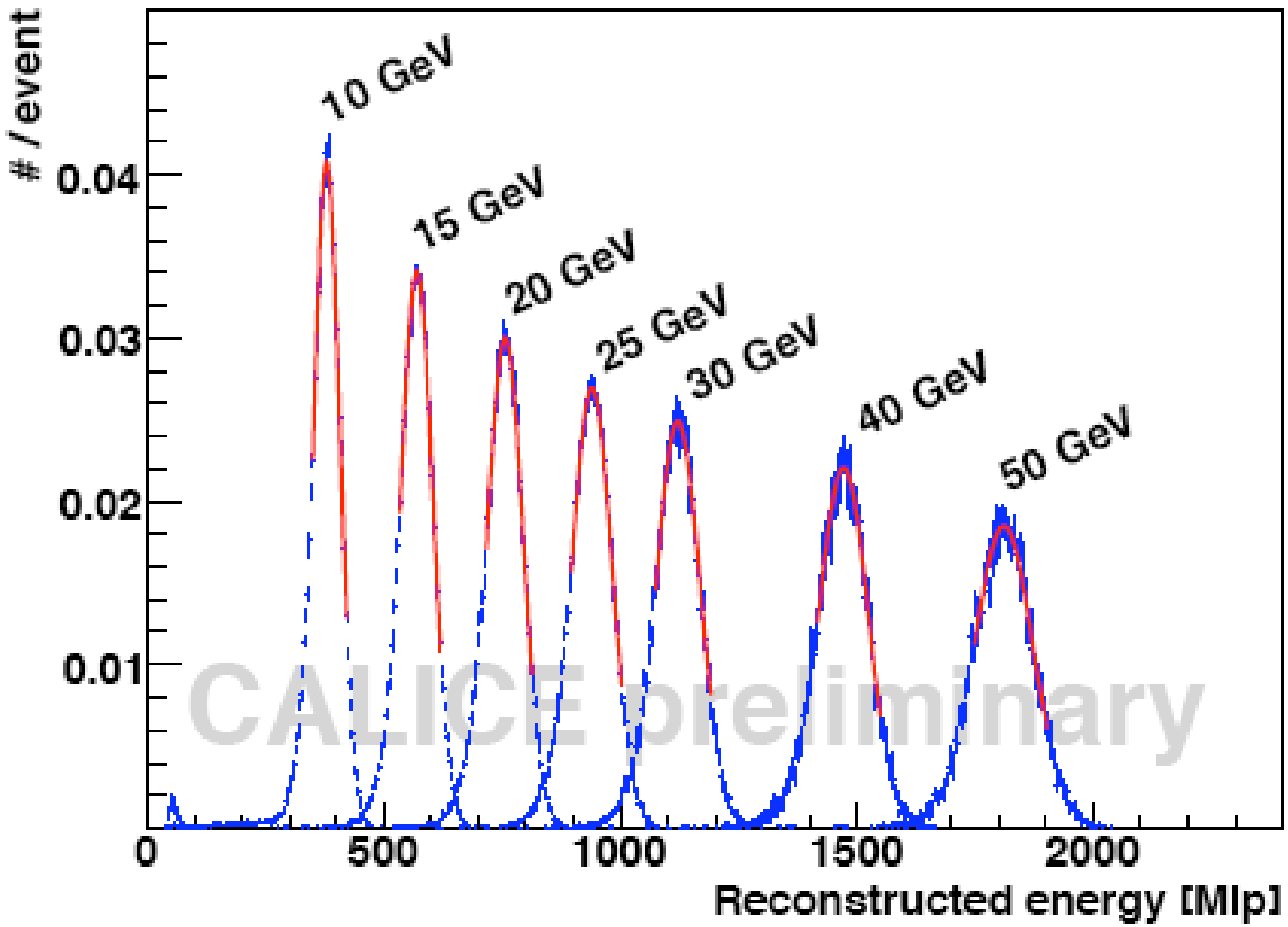
The power of imaging calorimeter



- The high granularity of the calorimeter allows detailed 3D studies of the substructure of hadronic showers
  - Minimum ionising track segments can be identified and used as a calibration tool
  - Highly granular readout provides detailed 3D information on hadronic showers to constrain shower models
- Strong support for particle flow algorithm

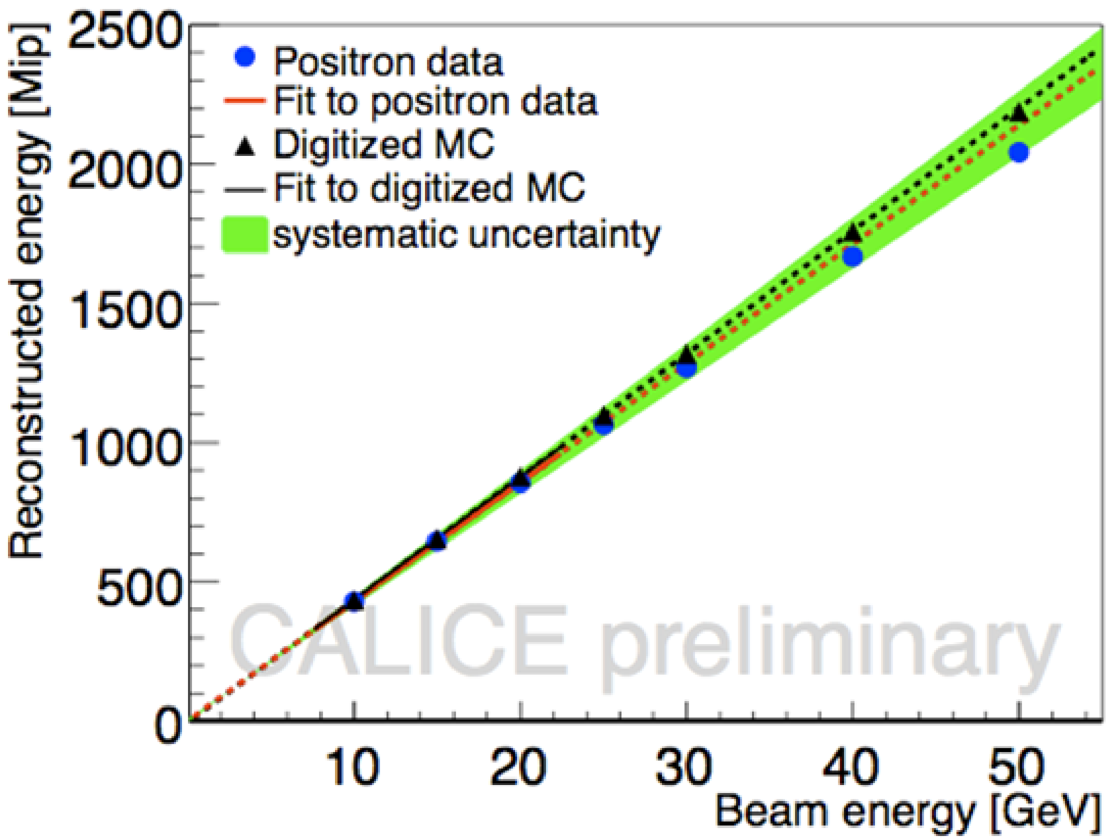
Validation with em showers

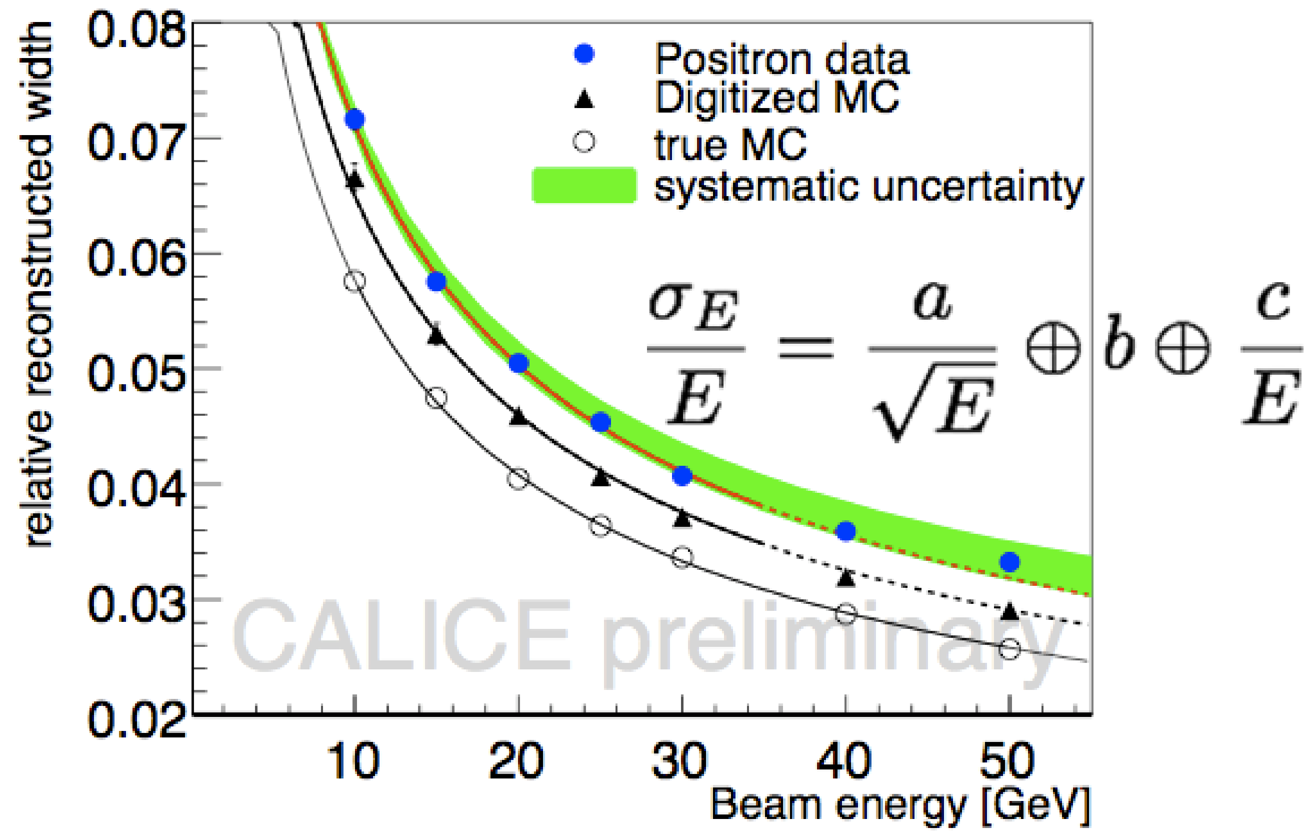
- Use electron data no ECAL in front to validate detector understanding and calibration



Validation with em showers

- Simulation includes p.e. statistics, SiPM non-linearity, electronic noise, light cross talk between tiles, and overlaid hits from random trigger events.

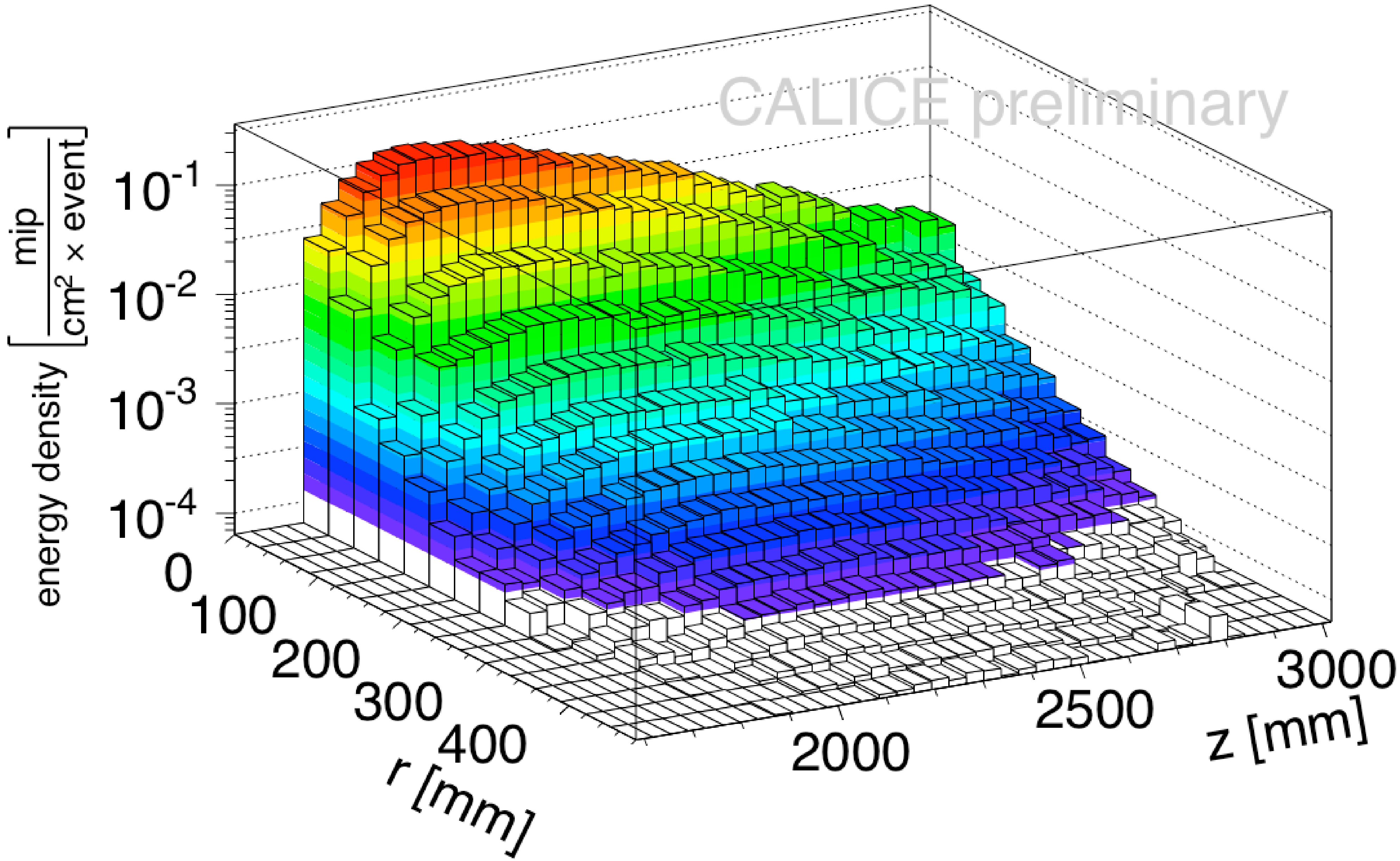




Non-linearity < 4% @ 50GeV, and improving ...

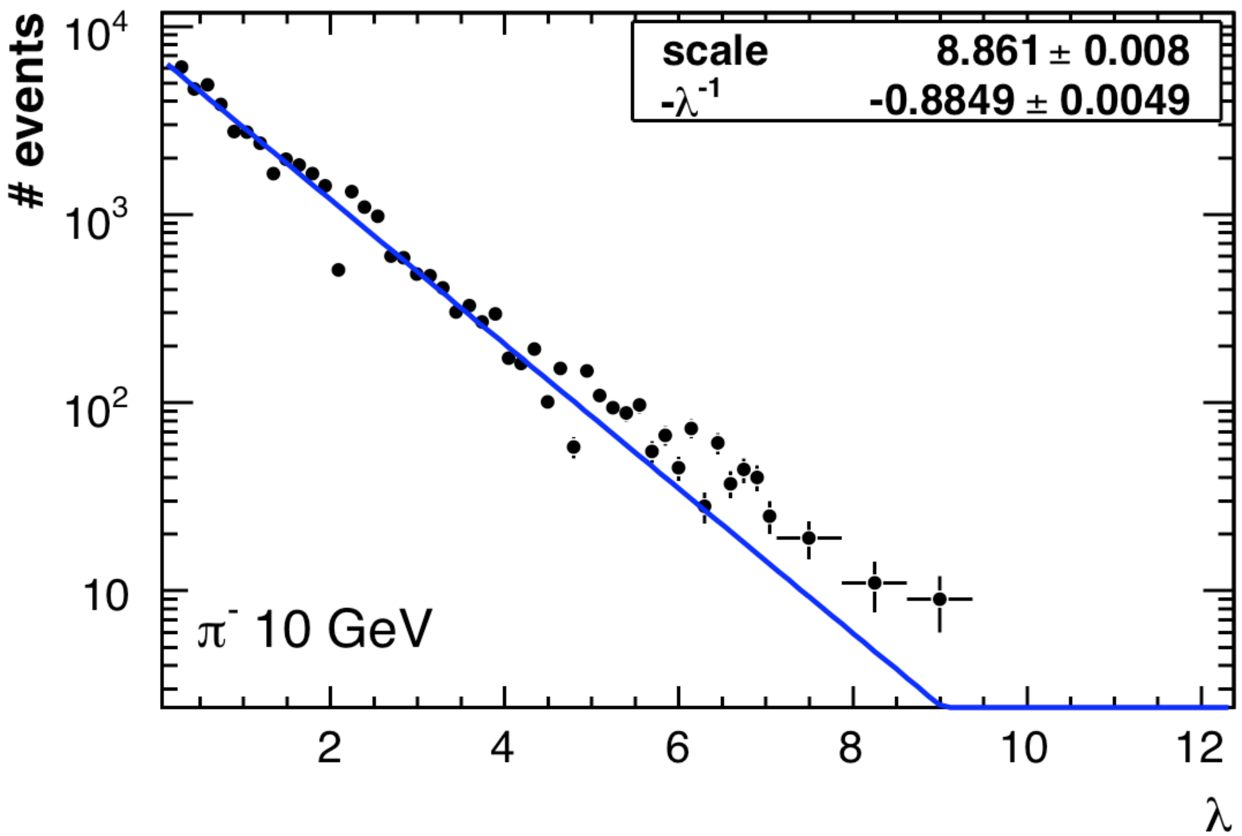
- Stochastic:
  data: a = 22.5 ± 0.1(stat) ± 0.4(syst)[%/√E]
  MC: a = 20.4 ± 0.2(stat)[%/√E]
- Constant term:
  data: b = 0 ± 0.1(stat) ± 0.1(syst)[% /√E]
  MC: b = 0 ± 0.6(stat) [% /√E]
- c fixed to ~ 60MeV (pedestal events)

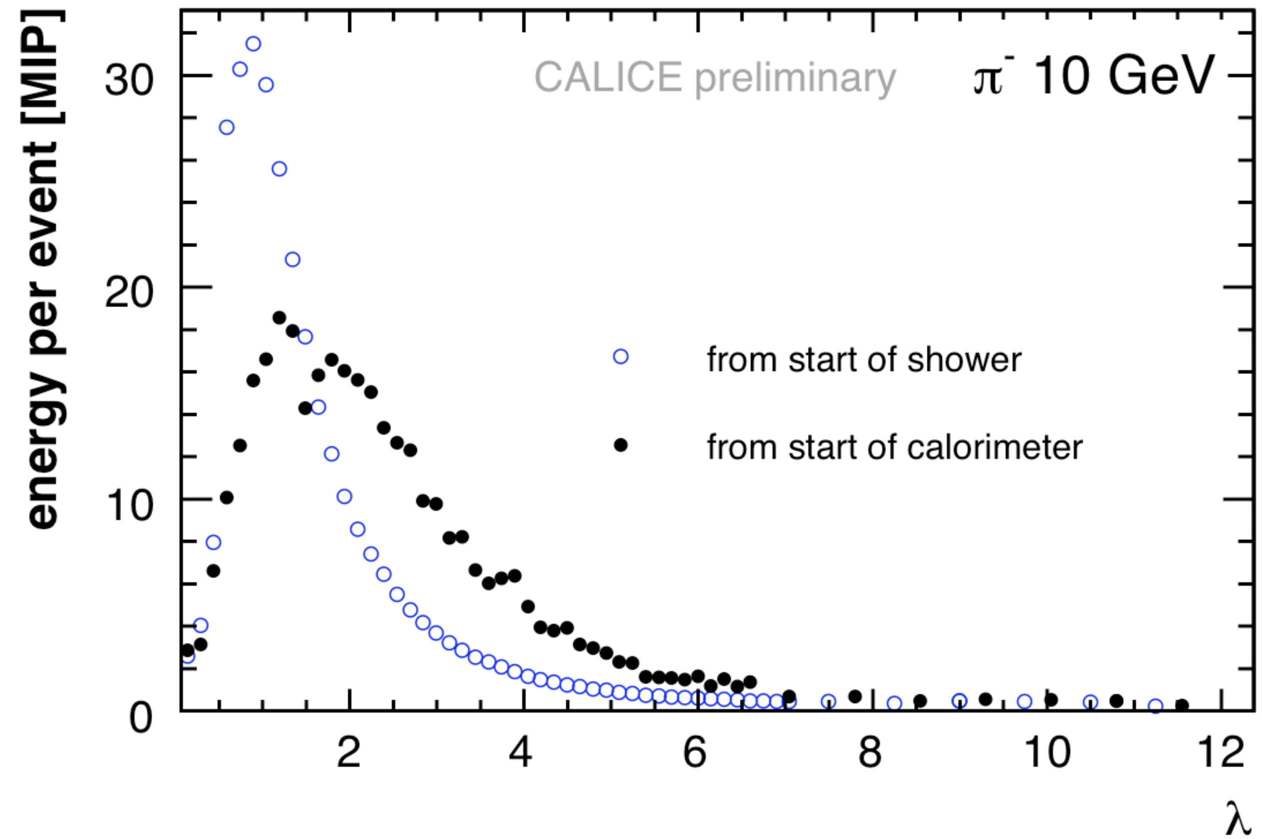
Two dimensional profiles



- Two dimensional radial energy density for 10 GeV negative pion showers
- Transversal radial ring with center r, and longitudinal position z

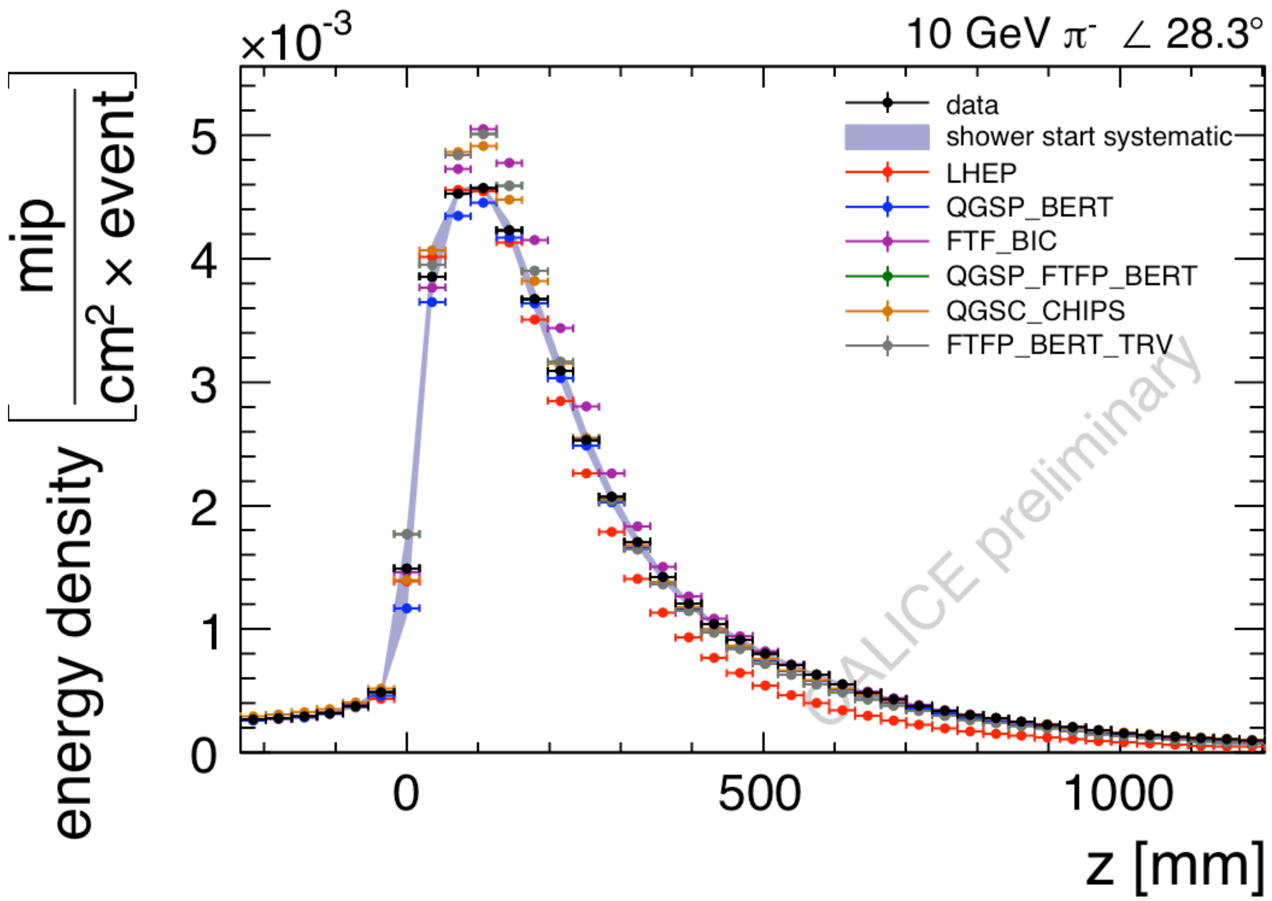
Position of shower start

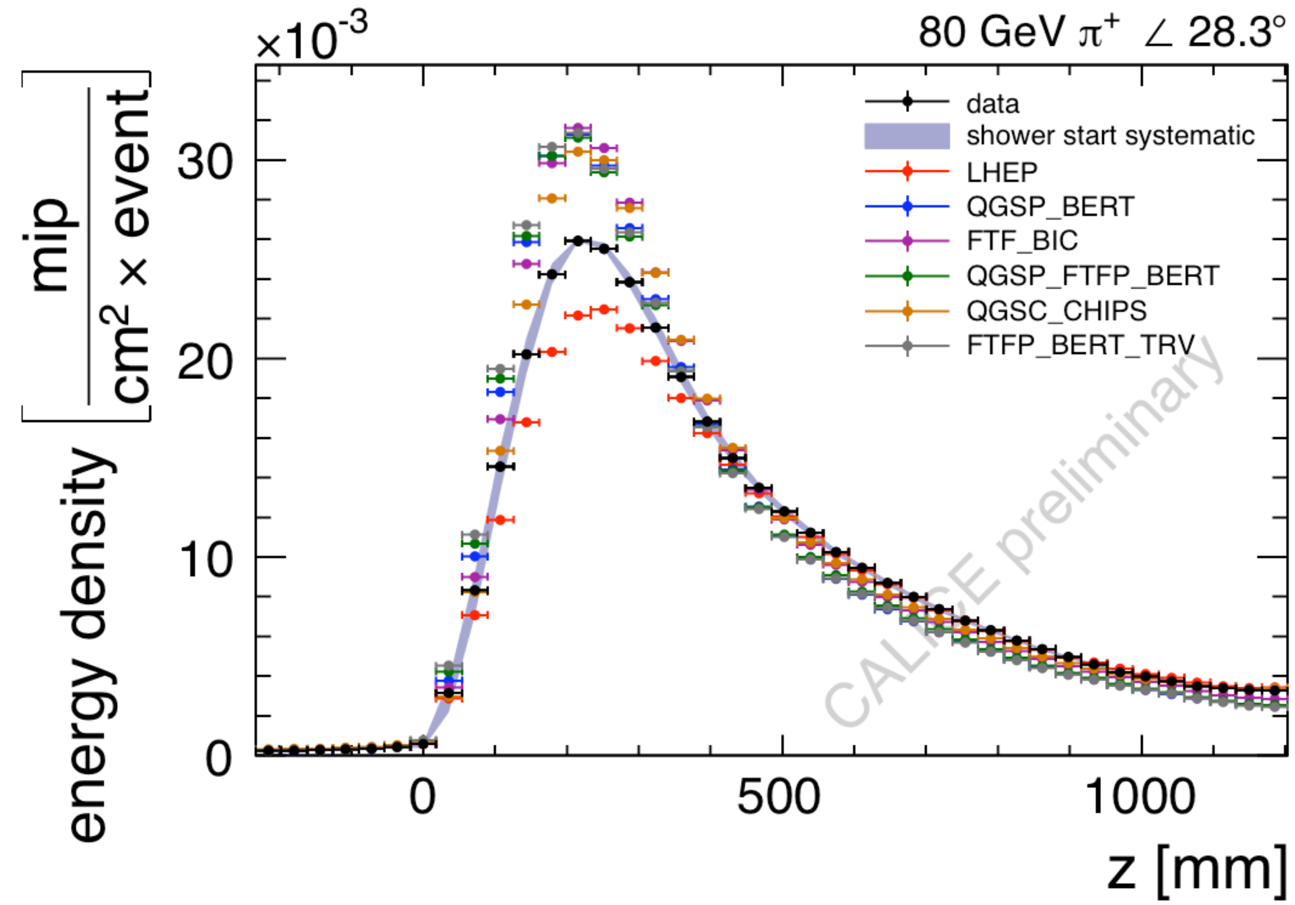




- Position of shower start in the calorimeter as a function of the number of interaction lengths
- Longitudinal shower profile in the calorimeter determined before and after the shift, event by event, to the shower starting point

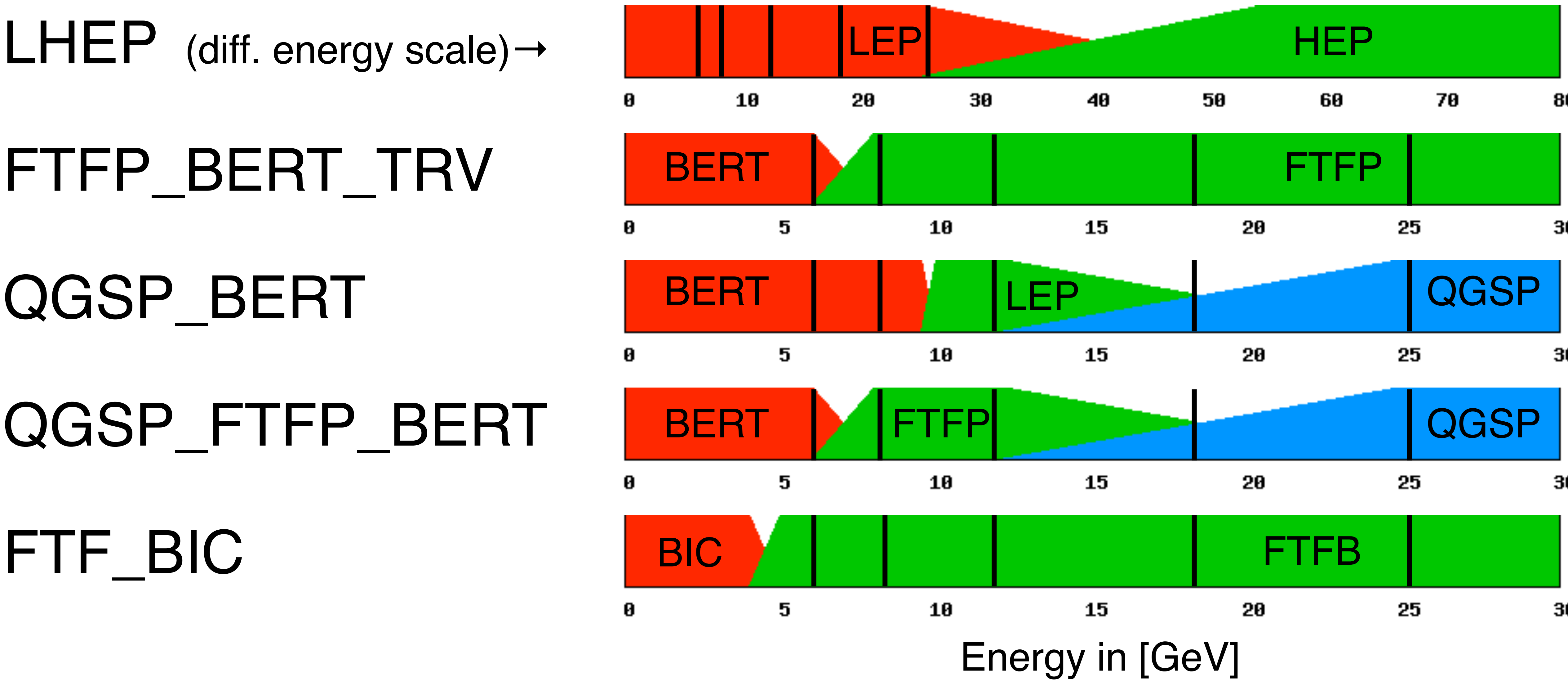
Longitudinal shower profile - data and MC





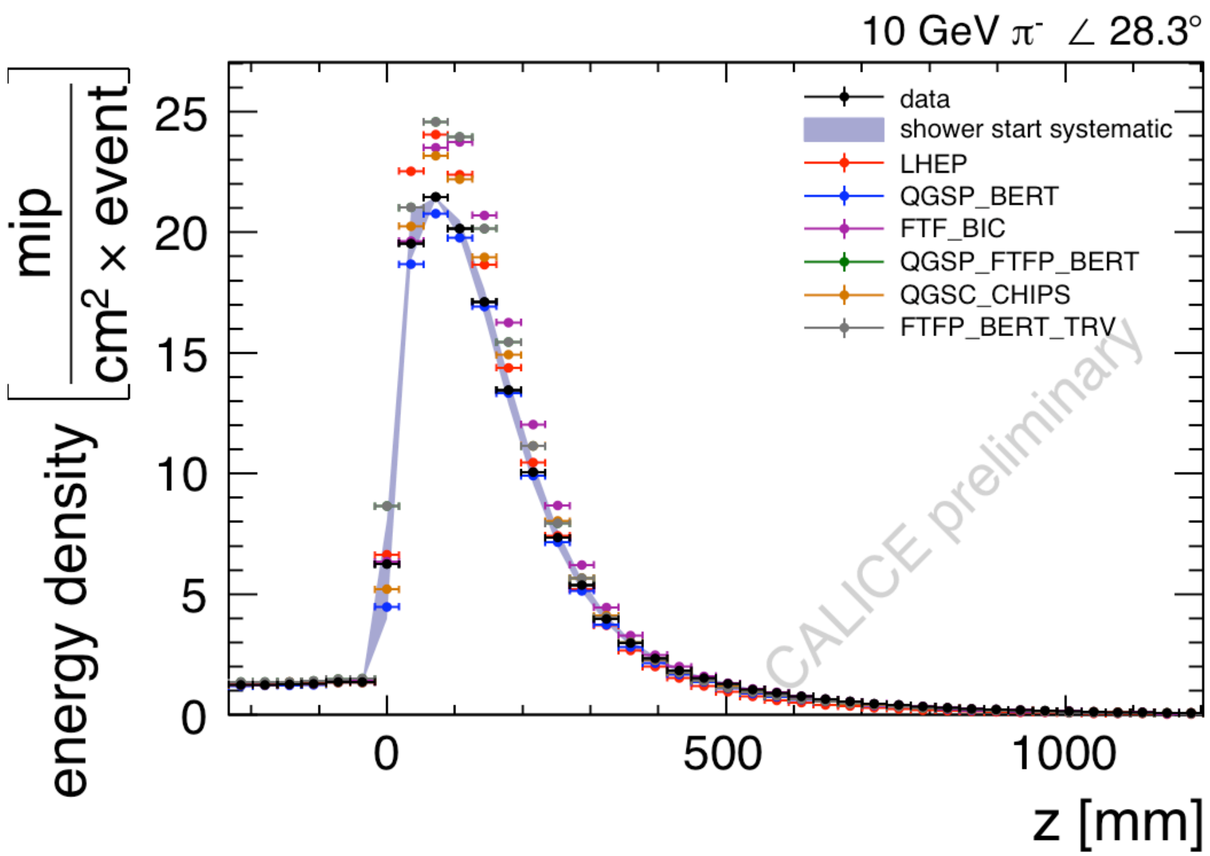
- From shower start
  - ➡ identification of the shower start, comparison of profiles to simulations without fluctuation of start position
- Agreement between data and simulation around 20%
- Most of the time, simulation above data in the shower core but below in the tails

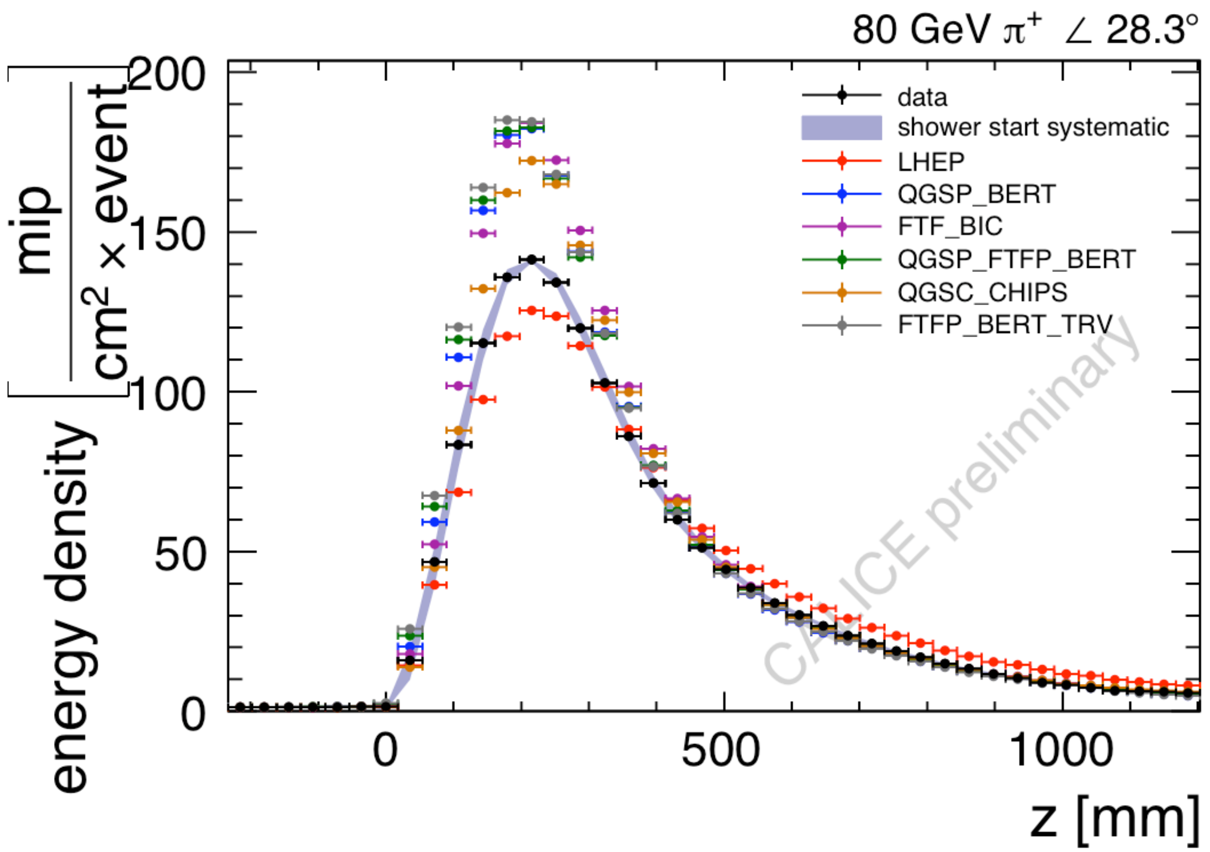
Monte Carlo Simulation models list



- Discrepancies spotted depending on model, beam energy, analysed observable
- Large differences observed between lists reflect uncertainties in current understanding of hadron showers

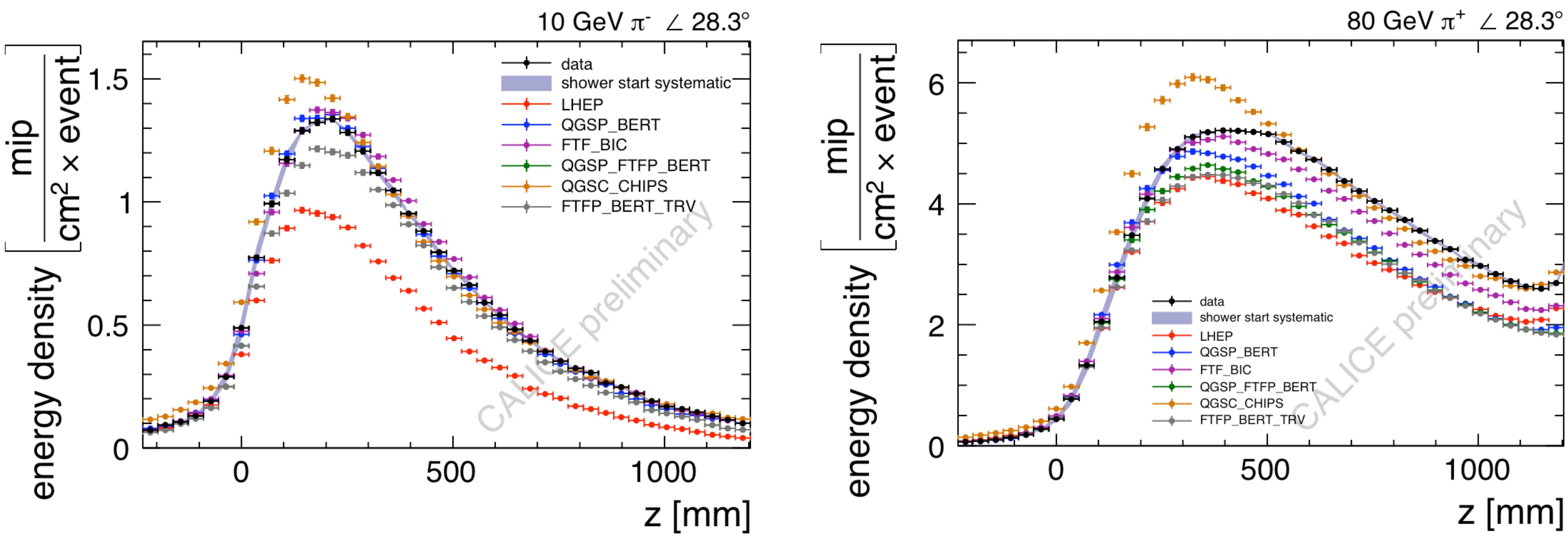
Longitudinal shower profile - data and MC





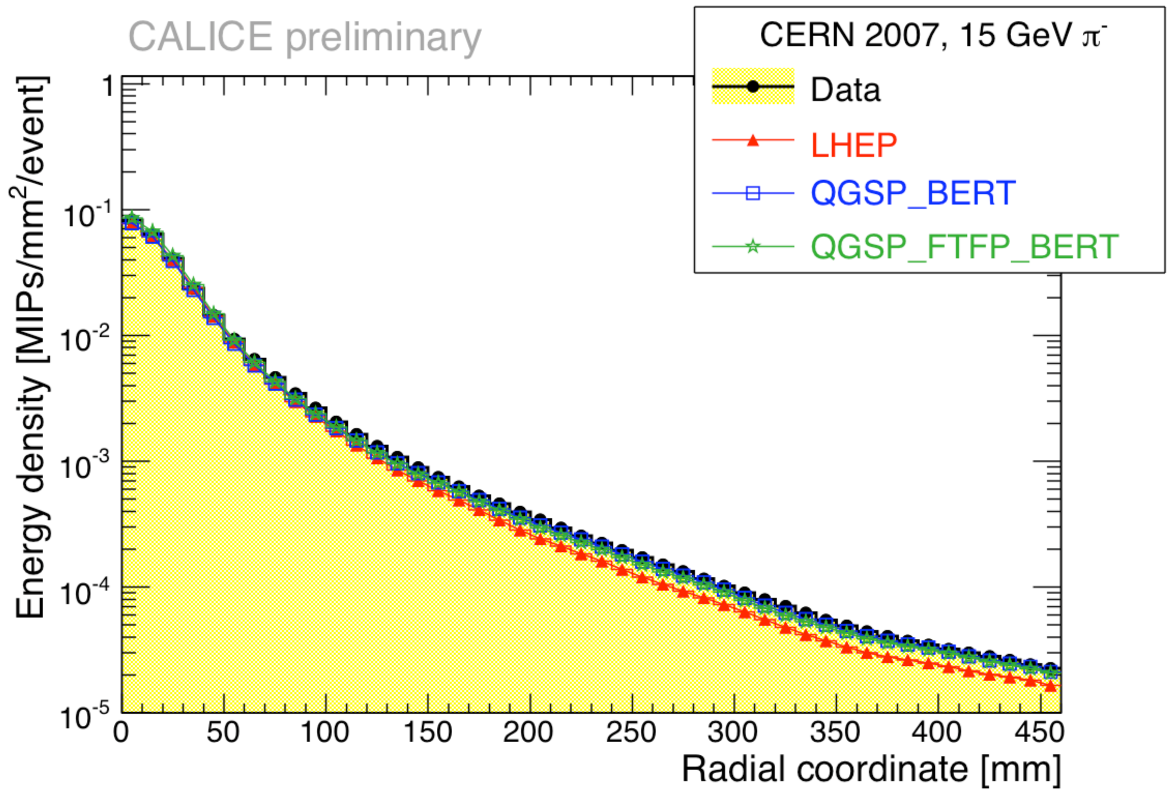
- Differential longitudinal profiles, 0 mm <= r < 60 mm from shower start
- Shower core, reflect the e.m. shower information

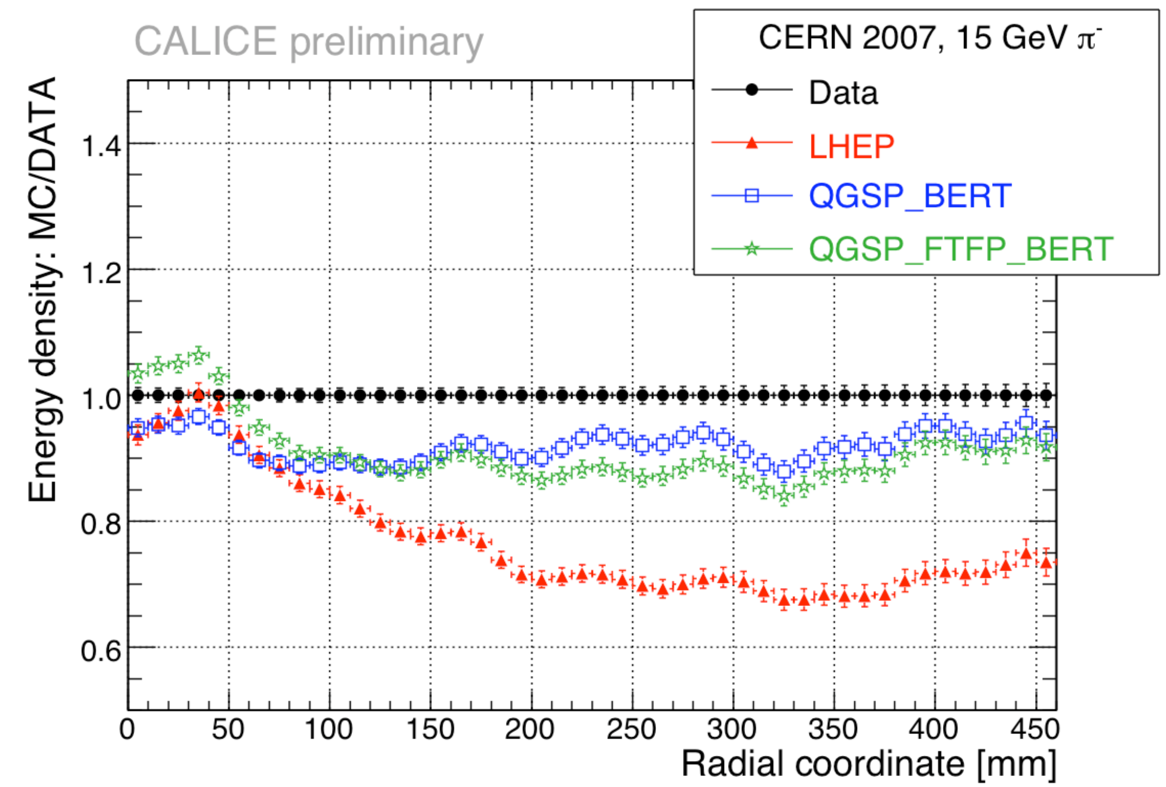
Longitudinal shower profile - data and MC

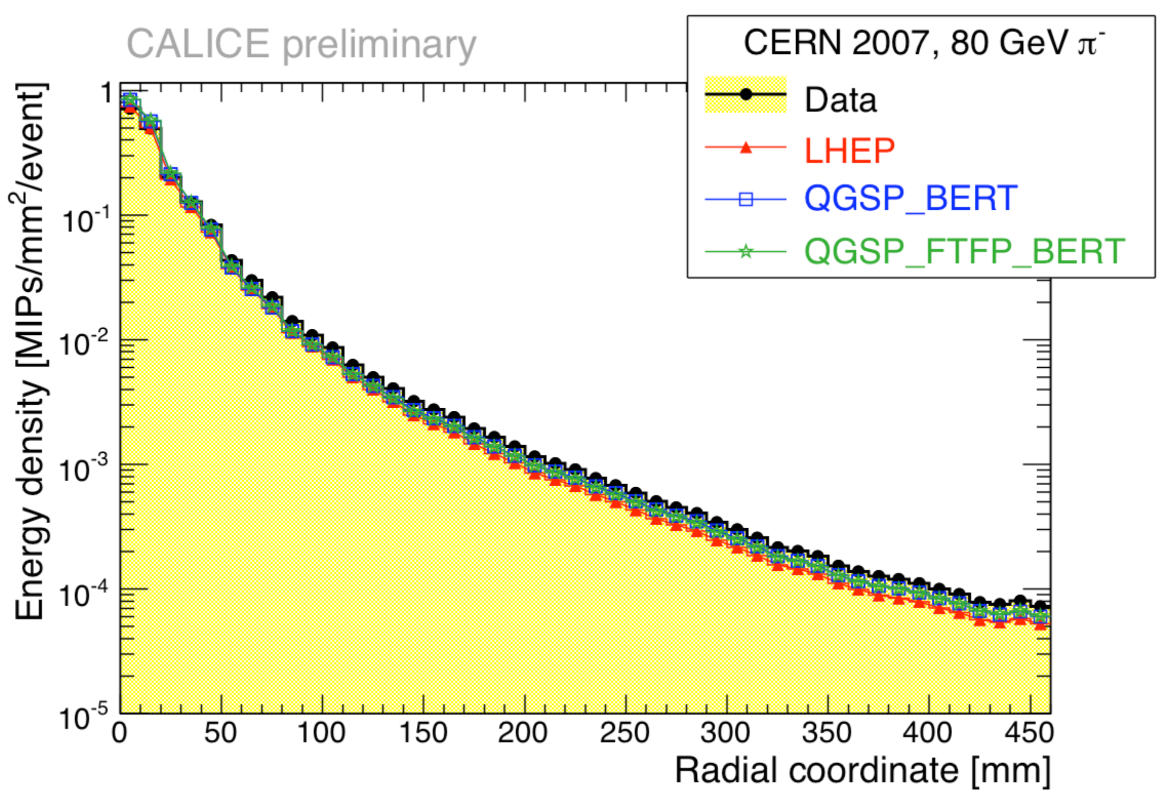


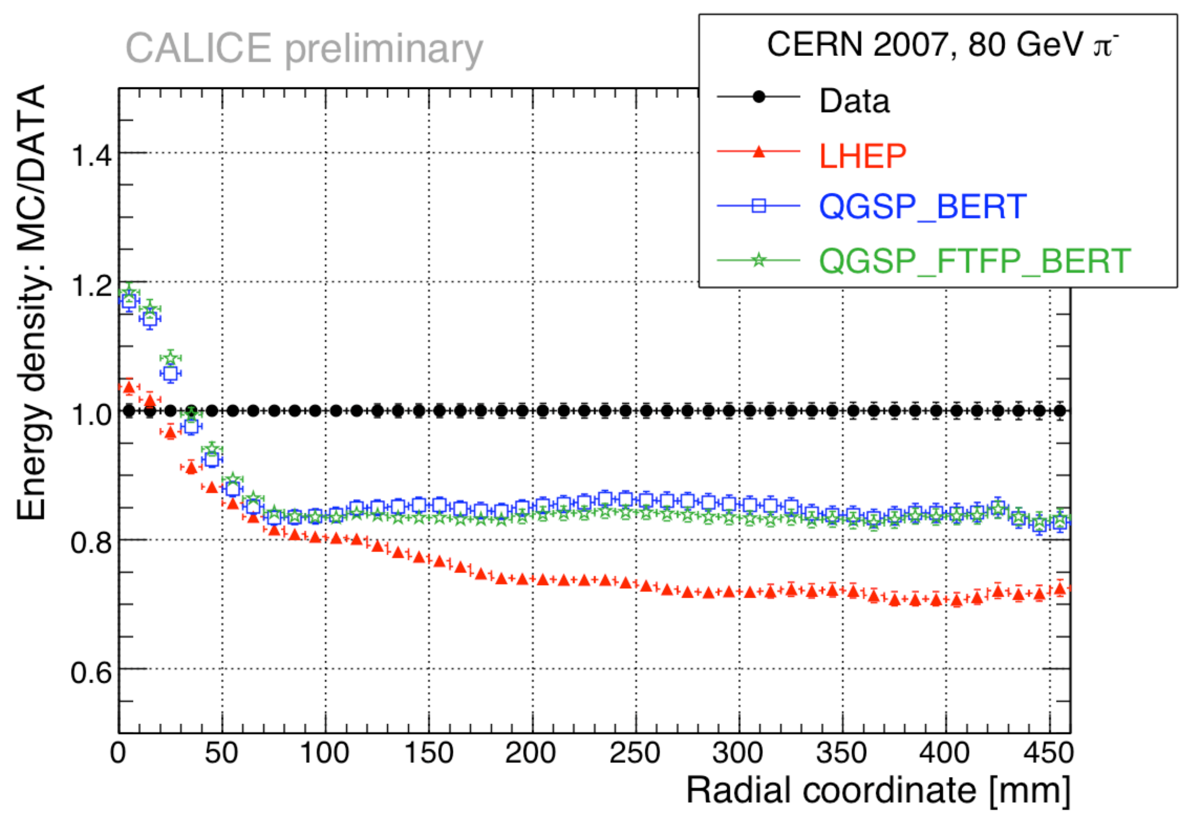
- Differential longitudinal profiles, 120 mm <= r < 180 mm from shower start
- Larger radius range , reflect the neutron information

Transverse shower profile - data and MC

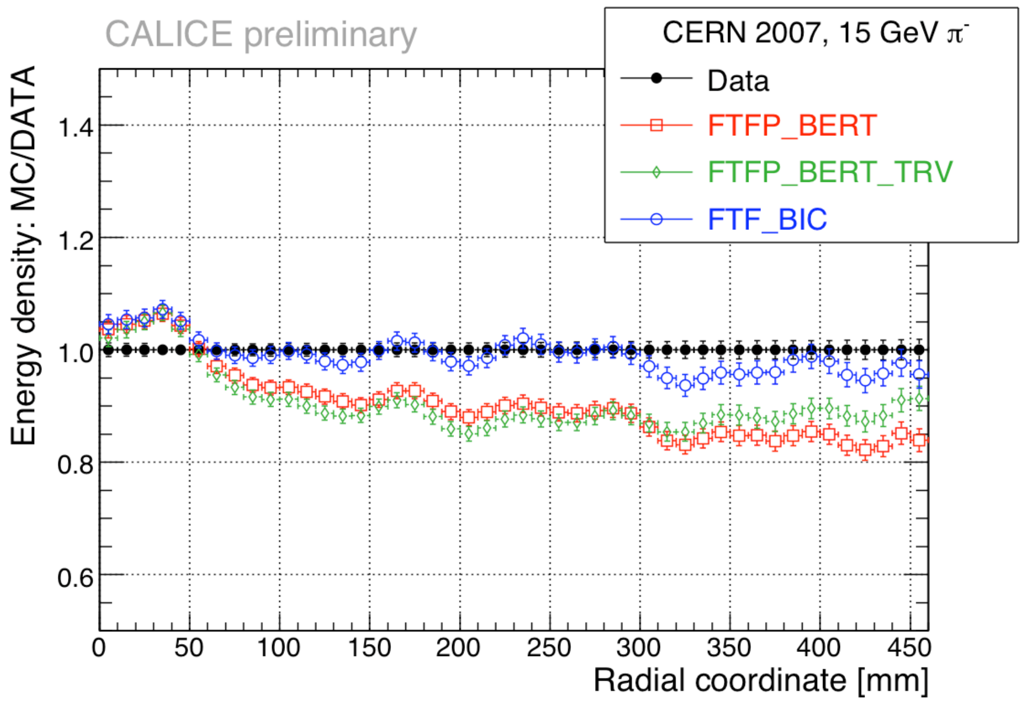


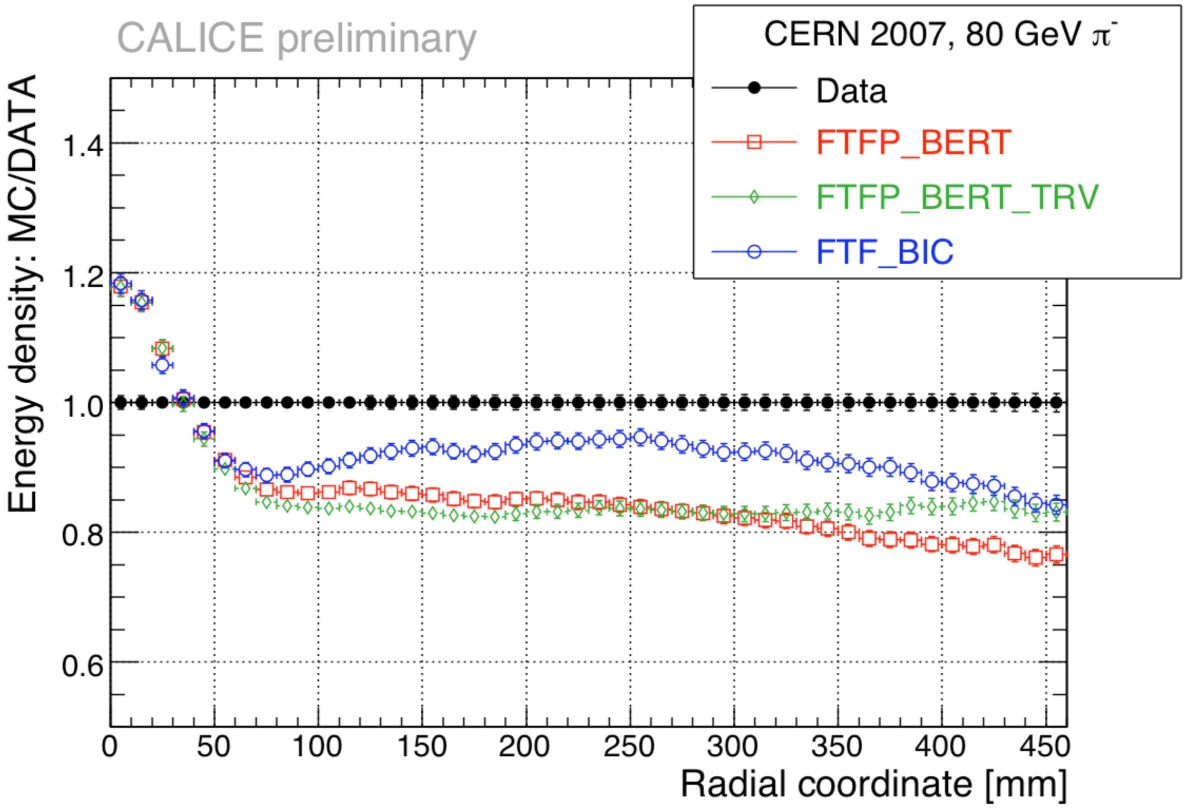






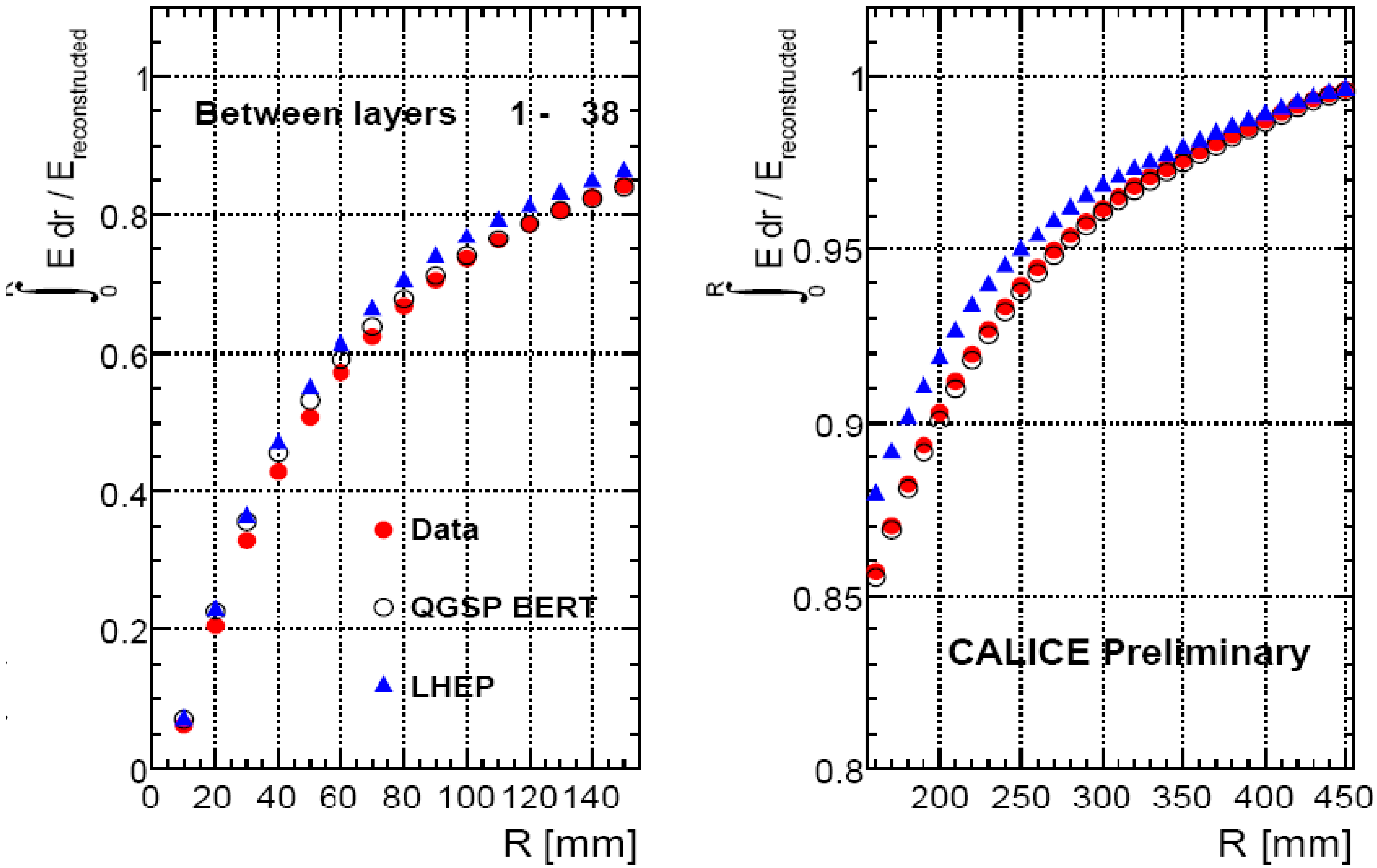
Transverse shower profile - data and MC





- Important shower property for particle flow performance
- Agreement between data and simulations around 20%
- Most of the time, simulations above data in the shower core but below in the tails
- Transverse profiles are not accurately simulated for electrons
  - ➥ Some of the disagreement for hadrons may be due to instrumental effects

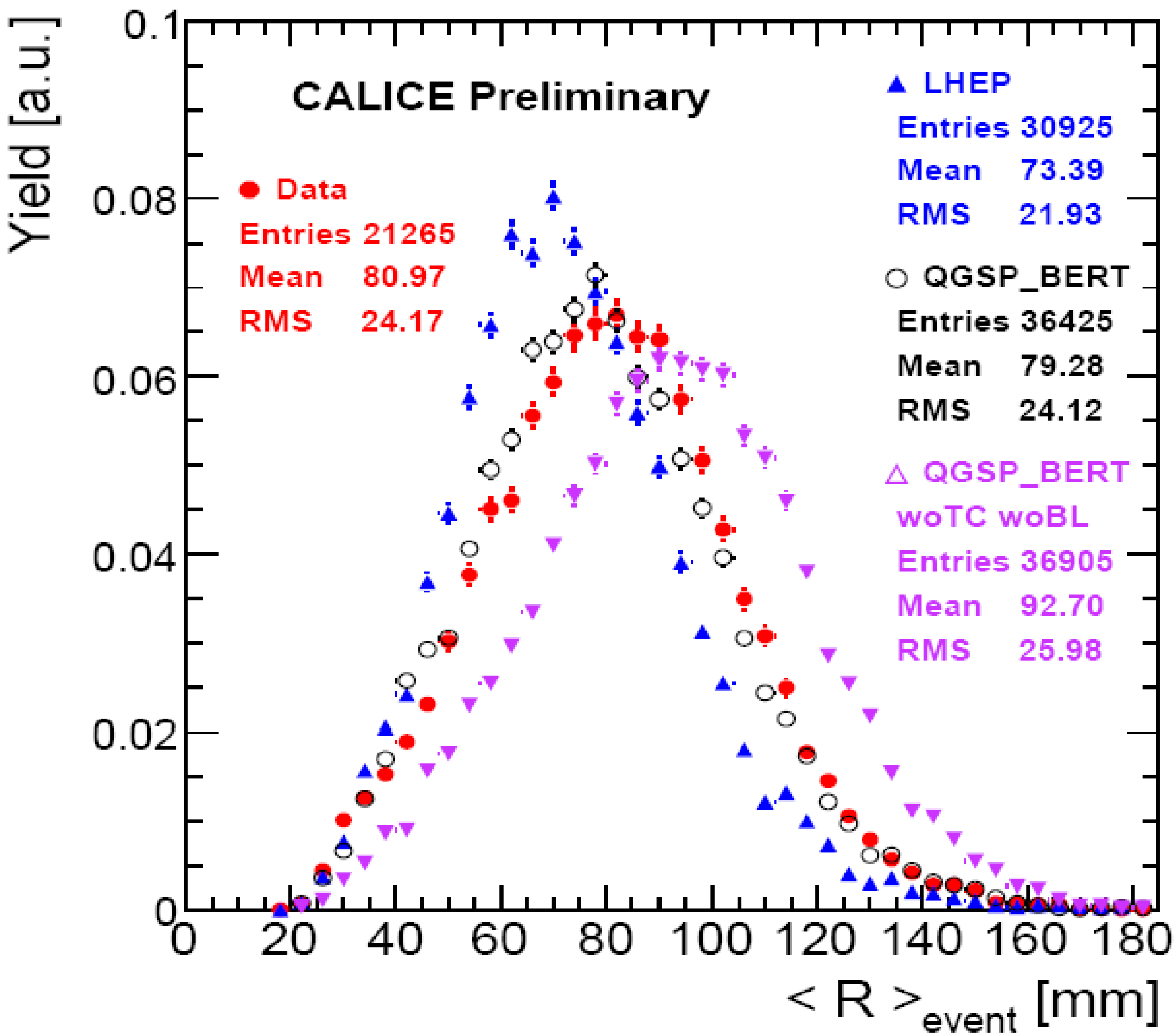
Transverse shower containment



- Integrated lateral energy fraction
- Core and tails well reproduced by QGSP_BERT

Mean shower radius

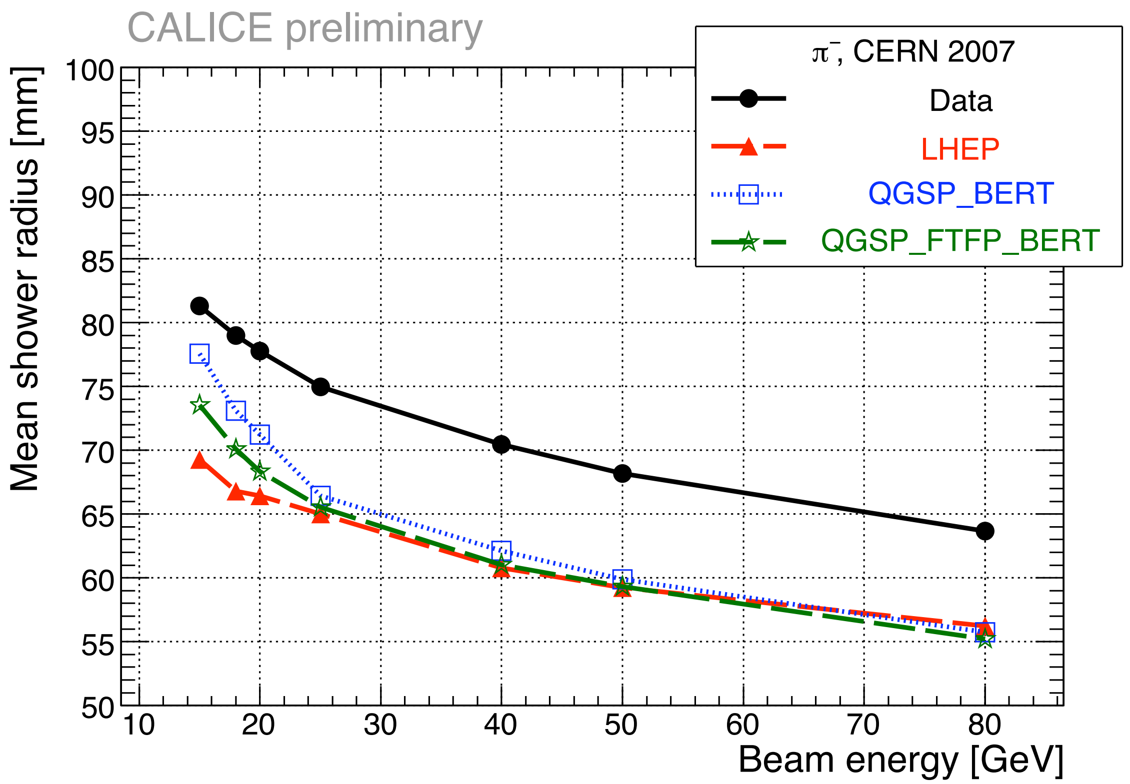
$$\langle R \rangle_{event} = \frac{\sum_i E_i \cdot R_i}{\sum_i E_i}$$

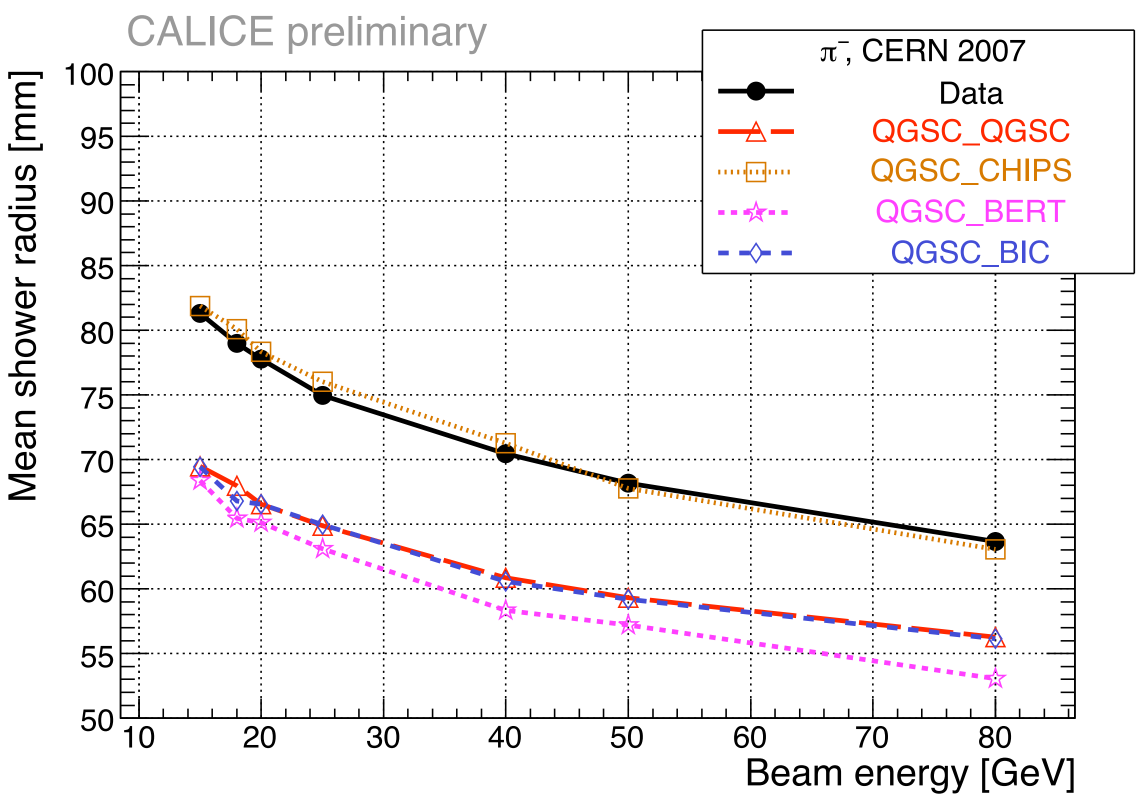


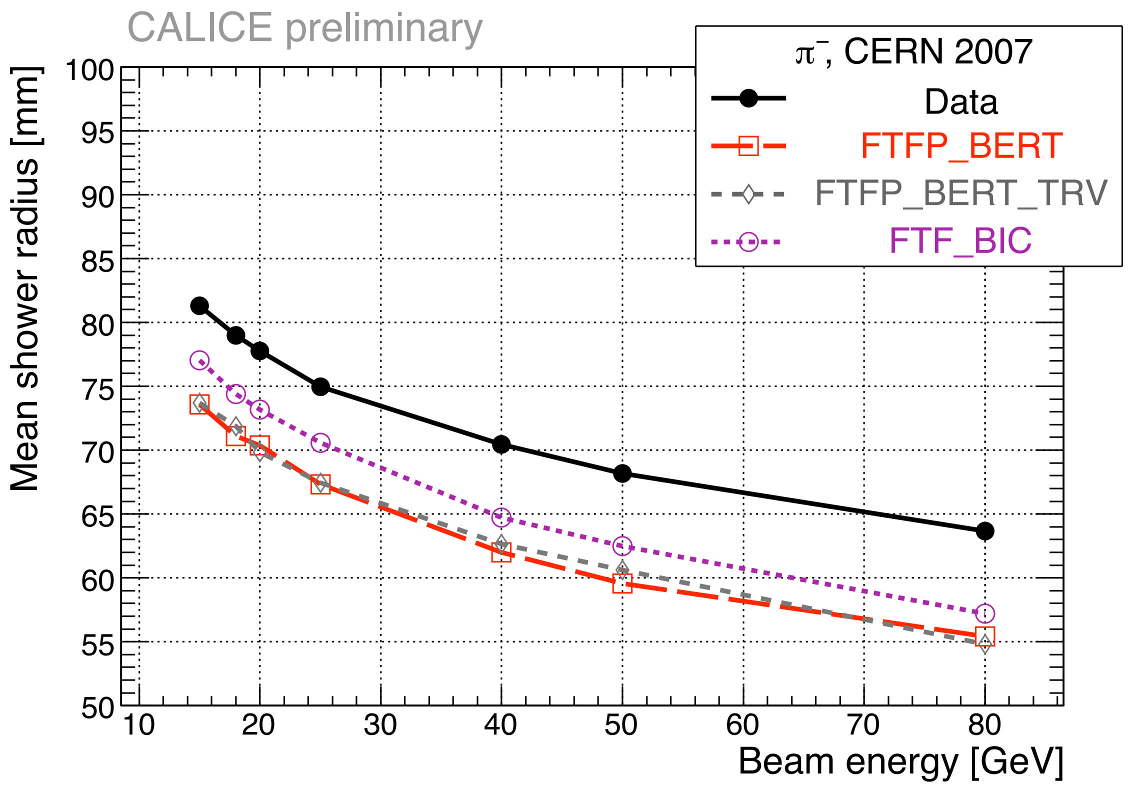
- Shower radius: distance between hit and shower axis weighted with energy
- Mean value and event-to-event fluctuations well described
- Proper treatment of neutrons in shower evolution and detector response critical

Mean shower radius

- Shower radius: distance between hit and shower axis weighted with energy
- Showers become narrow with increasing energy

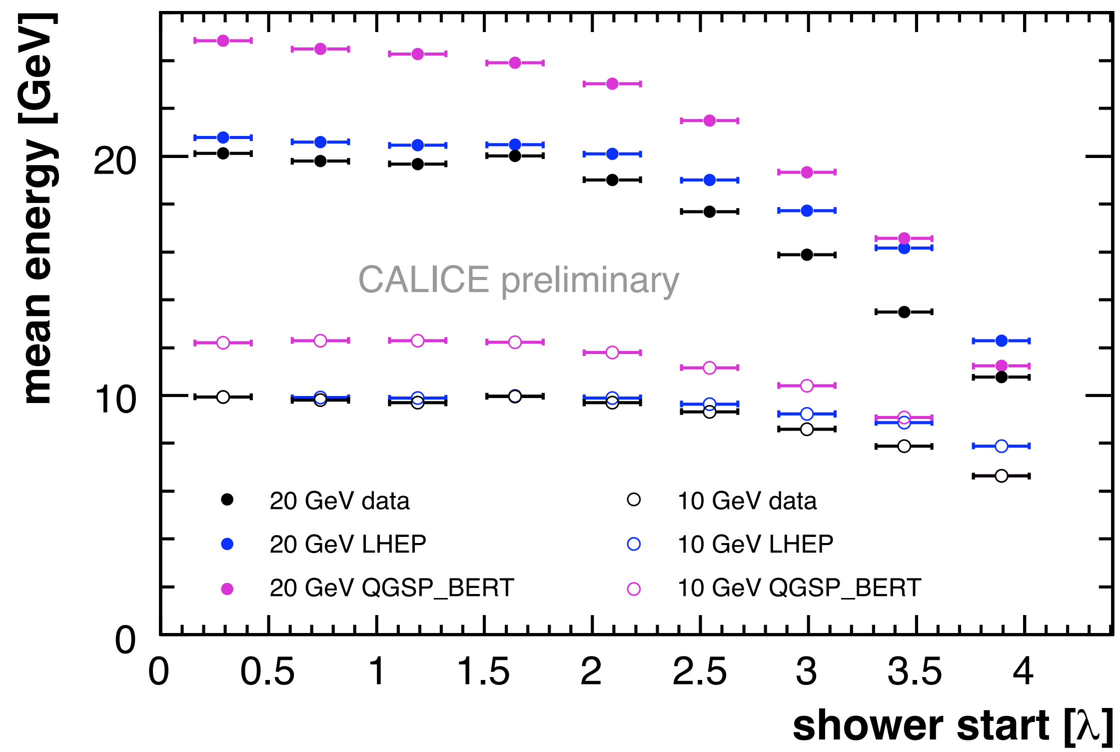


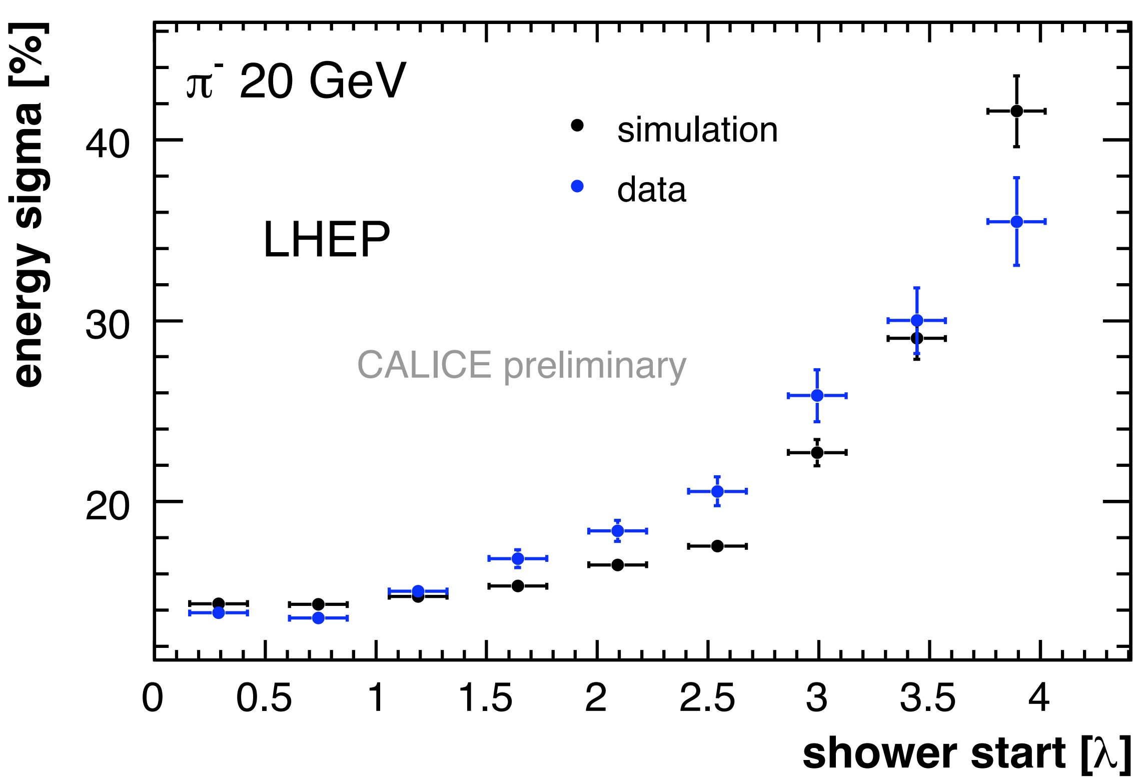


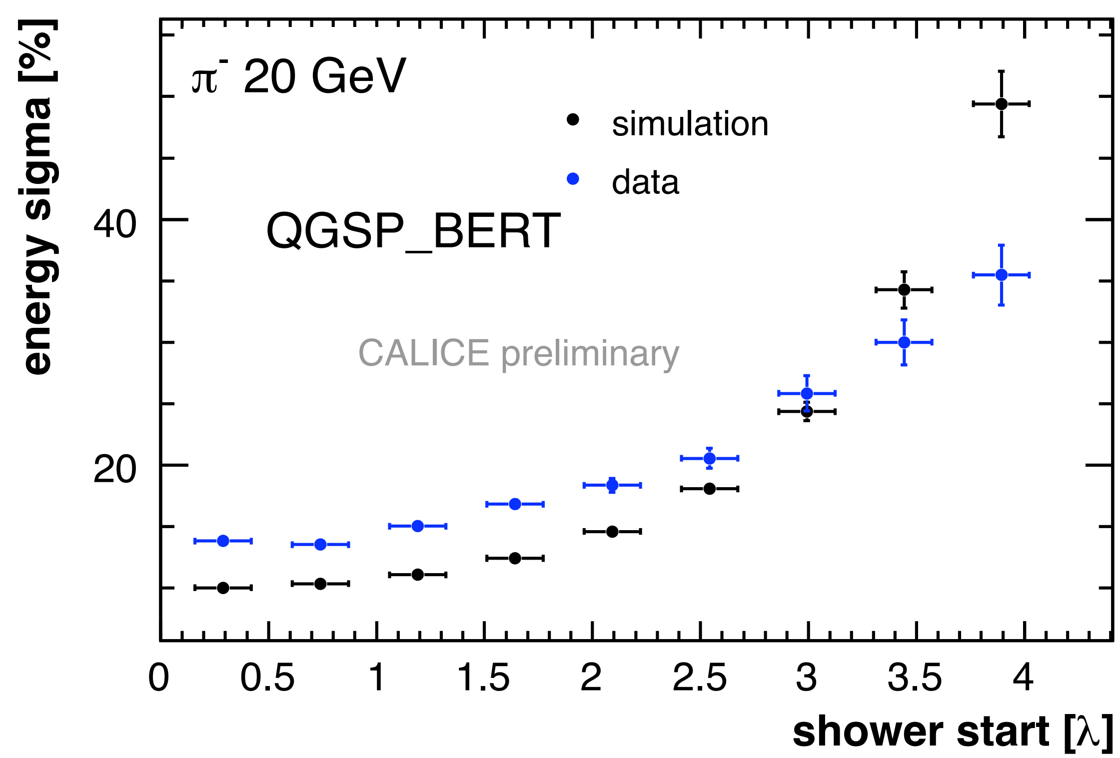


Leakage

- Leakage: shower start dependent energy and resolution
- The later the shower starts the more likely leakage is
- Reconstructed energy decreases and resolution worsens







Summary

- CALICE had very successful test-beams
- Detector understanding is steadily increasing
  - The SiPM technology has proven to be robust and stable
  - The calibration is well under control
  - The performance is as expected and understood
  - ➥strong support for predicted PFLOW performance
- Promising measurement of shower shapes
  - improved sensitivity due to shower start
  - high granularity allows very detailed studies
  - agreement between simulations and data is around 20%
- Analysis on going: stay tuned, more to come from CALICE